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# *ENERGY COST AND POST-EXERCISE EFFECTS OF A PROLONGED, HIGH RATE OF FIRE, HOWITZER SIMULATOR TRAINING EXERCISE*

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**13. ABSTRACT** *(Maximum 200 words)*
The energy cost and continued effectiveness of 155 mm Howitzer crewmen during a 45 hour exercise with high rates of fire (640 rounds/day) were examined. Energy cost was estimated from heart rate. Additional measures included profile of mood states (POMS), rating of perceived exertion (RPE), rating of pain, soreness and discomfort, arm-hand steadiness, handgrip strength and time to mission completion. Energy cost and time to mission completion decreased significantly over the 45 hours, as did handgrip strength. POMS revealed an increase in fatigue and tension and a decrease in vigor. RPE increased significantly, as did upper body pain soreness and discomfort. Arm-hand steadiness was not affected. Overall results indicated that high rates of fire could be maintained for a 45 hour period with little effect on objective measurements, and with a significant decrease in time for task completion and energy cost. RPE, POMS and perception of pain, soreness and discomfort were all negatively affected by continuous operations, as was handgrip strength. While howitzer loading performance was not affected, these factors may become more important in longer training exercises.

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# FOREWORD

Peacetime military training must be rigorous and realistic if soldiers are to maintain military readiness. The price of realistic training is high--both in terms of injuries to soldiers (7) and the cost of equipment and materials. These problems are exacerbated in equipment-heavy units, such as the field artillery. Handling heavy rounds and digging the gun in and out of position are activities with a high risk of injury. The cost of firing a single round from a 155 mm Howitzer is $360. With the addition of fuel and maintenance costs, live fire training is a very expensive activity.

One way to reduce the high cost of training is the use of simulators, but these have not been generally available. In 1989, a prototype 155 mm Howitzer simulator was tested at Ft Sill, OK. USARIEM participated in testing the simulator by measuring energy cost and fatigue of soldiers during a 45 hour exercise. This report describes the results of this study.

# EXECUTIVE SUMMARY


This study examined the energy cost of 155 mm Howitzer crewmen during a 45 hour exercise with high rates of fire (640 rounds/ 24 hour period). The energy cost of different rates of loading the howitzer were measured, and used to develop a prediction equation for oxygen uptake from heart rate for each individual. An estimation of the energy cost of 6, 75 minutes of howitzer loading was made by collecting continuous heart rate during the exercise. Subjective measurements made during the exercise included profile of mood states (POMS), rating of perceived exertion (RPE) and subjective pain, soreness and discomfort. The objective measurements made were arm-hand steadiness, handgrip strength and time for task completion (time elapsed from fire mission call in to mission completion, summed for over 75 min). Muscle strength, aerobic capacity, body composition and anthropometric measurements were made and correlated with howitzer loading performance.

There was a significant decrease in predicted energy expenditure from cycle 1 to cycle 6. The time for task completion decreased significantly ($p<.01$) from 28.1 min during cycle 1 to 24.3 min during cycle 6. The POMS revealed a significant increase in fatigue and tension, and a decrease in vigor ($p<.05$). There was a significant increase during the 45 hour exercise for upper body, lower body and overall RPE ($p<.05$). The pain, soreness and discomfort questionnaire results revealed a significant increase in muscle soreness in the hand, arm and shoulder areas ($p<.05$). The high intensity loading exercise did not affect arm-hand steadiness. There was a small, but significant decrease (8.6%) in isometric handgrip strength from cycle 1 to 6.

Overall results indicated that high rates of artillery fire could be maintained for a 45 hour period with little effect on the objective measurements made, and with a significant improvement in time for task completion. Ratings of perceived exertion, pain, soreness and discomfort and profile of mood states were all negatively affected by the continuous operations, as was isometric handgrip strength. While howitzer loading performance of 45 hours did not decay, the changes in both objective and subjective measures suggest longer exercises may negatively affect performance.

# INTRODUCTION

Loading and firing of a 155 mm Howitzer is a manpower intensive task that has no counterpart in the civilian world. Crew members must lift, load and fire 45 kg shells. The loading procedure is a complex process and for rapid fire missions is performed at high speed, with significant potential for injury. In a realistic operation, a 9 man crew may be expected to load and fire 500+ rounds and move the howitzer 17 times in a single day (29). In the Falklands, five artillery batteries fired the equivalent of a regiment's training ammunition for 4 years in a 12 hour period (2).

The job of a field artilleryman is one of the most physically demanding in the Army, yet few studies have systematically examined the physical demands on the crewmembers. The studies performed thus far have focused on soldier performance during actual field artillery operations. In 1986, howitzer crewmen were studied during an eight-day sustained operations field training exercise (11,23). Approximately 75% of the fire missions were "dry" meaning the round was not actually chambered and fired. For all dry fire missions, the soldiers were instructed to lift the round into and back out of the hydraulic ram. Since it was not possible to continuously observe each gun, it is not known if the round was actually lifted for each dry fire mission. Sleep was monitored and controlled by the crew chief, with the average soldier receiving 5.3 hours each day. Patton et al. (23) found no evidence of physical fatigue, and in fact, found increases in handgrip and lifting strength at the end of the exercise. In another study that used a similar 8 day field artillery exercise (15), soldiers averaged 3-4 hours of sleep during each 24 hour period. There was a significant decrease in isometric handgrip strength during the training exercise. Sleep deprivation has not previously been shown to result in strength decreases (27). The resupply of a howitzer has been modeled in the laboratory (24), but this model did not use the same movements and equipment as those used in actual howitzer operations.

The energy cost of actual howitzer operations has not been measured, mainly due to logistical difficulties of using equipment to measure energy cost in the field. In 1989, a prototype 155 mm Howitzer simulator was located at Ft Sill, OK, and made available for testing. The simulator allowed physiological

measurements to be made while soldiers performed the tasks involved in loading and firing the howitzer. In the simulator, as in an actual gun, the round was loaded onto a tray, and chambered (hydraulically or manually), the powder was inserted, the breech was closed, the ignition charge was placed and the lanyard was pulled to fire the gun. The major differences between the simulator and the actual howitzer were, for the simulator: 1) the round was hydraulically expelled from the gun instead of being fired, 2) the round was not charged before loading, 3) the powder was expelled as the gun was swabbed, and 4) there was no smoke or blast. From a performance viewpoint, the only real difference was that the powder bag was still in the gun and was swabbed out after the gun was fired.

The simulator provided a safe, controlled environment for the study of howitzer crew performance. Accurate energy expenditure rates for various rates of fire would be useful in determining work rest schedules for gun crews, optimizing crew size, and designing equipment. The purposes of this study were 1) to measure the energy cost of loading and firing a howitzer simulator during a simulated field exercise at a high rate of fire and 2) to determine if performance could be maintained for a 45 hour period.

# METHODS

## SUBJECTS

Eighteen experienced field artillery crewmen volunteered to participate in this study. All were briefed, then read and signed an informed consent statement. All were examined by a physician and medically cleared to participate.

## STUDY DESIGN

The study consisted of one week of pre-exercise testing and training. Following the pre-exercise week, soldiers participated in a 45 hour continuous

operations simulator exercise, conducted in the 155 mm Howitzer simulator. Two 45 hour continuous operations exercises were conducted with 9 soldiers participating in each. Soldiers were given the opportunity to sleep during the two, consecutive 1-1/2 hour rest periods every 7.5 hours. A minimum of 2 days rest was provided between pre-exercise testing and the 45 hour exercise.

## PRE-EXERCISE MEASUREMENTS

### Body Composition

An estimation of body composition was made utilizing the current Army circumference method. The neck circumference was measured just below the larynx. The abdominal circumference was measured at the level of the umbilicus (30).

### Anthropometry

Anthropometric measurements included: 1) leg length (the vertical distance from the floor to the level of the greater trochanter); 2) arm length (the distance from the acromium process to the tip of the middle finger); and 3) seated height (the vertical distance from the sitting surface to the top of the head) (6).

### Peak oxygen uptake

A determination of peak $\dot{V}O_2$ for howitzer loading was made to describe the aerobic capacity of the subjects as well as the relative exercise intensity during the 45 hour exercise. The test consisted of four loading bouts of increasing intensity. For the first three exercise intensities, subjects loaded at rates of 6, 7 and 9 rounds in five minutes. For the maximal exercise intensity, subjects were asked to load 10 rounds as quickly as possible. To give pacing feedback to subjects, test administrators provided round times to ensure maintenance of the loading rate. Subjects breathed through a low resistance two-way Hans-Rudolf valve and expired gases were directed into an on-line gas analysis system. A mouthpiece and nose clip were in place throughout the lifting exercise. Expired gas samples were collected continuously and averaged in 30 sec intervals.

Expired gases were analyzed for $CO_2$ and $O_2$ concentrations with Beckman LB-2 and Applied Electrochemistry S-3A gas analyzers. Volumes were measured with an in-line KL Engineering Company turbine. The peak $\dot{V}O_2$ test is described in more detail in a separate report (26).

During the peak $\dot{V}O_2$ test, heart rate was recorded continuously and averaged over 15 second intervals using the UNIQ heartwatch (Polar Electronics, Finland). A small transmitter unit was snapped over a pair of electrodes on an elastic strap which was placed securely around the chest. A receiver worn as a wristwatch recorded the signals sent from the transmitter. This information was downloaded to a desktop computer and stored on disk for later analysis.

## Measures of Muscular Strength

Four measures of strength were made: isometric handgrip, bench press, prone row and dynamic lifting strength. Isometric handgrip strength of the right hand was measured in a seated position (28). A mean of the best two of three trials was selected as the final score. Measures of maximal bench press and prone rowing strength were made in an on-post fitness facility. Following a warm-up, weight was added with each attempt, until the subject was unable to complete the lift. Bench press was measured on a Universal gym apparatus (Cedar Rapids, IA). Prone rowing was measured by having subjects lie face down on an elevated weight lifting bench. A loaded lifting bar was placed below and perpendicular to the lifting bench. Subjects were required to grasp the bar with both hands and lift it up to the bench bottom. Lifting strength was measured on an incremental lift device. Subjects lifted handles attached to a weight stack from the starting position to 152 cm above the floor. Additional weight plates were added with each attempt, until the subject was unable to complete the lift (18,28).

## Army Physical Fitness Test

A standard Army Physical Fitness Test was administered to all test subjects. The test consists of a timed 2 mile run, the number of sit-ups completed in 2

minutes and the number of push-ups completed in 2 minutes. The standard Army method of scoring each event on a 0-100 scale will also be reported. Subjects were asked to exert maximum effort during each event.

### Arm-hand Steadiness

The arm-hand steadiness test consisted of holding a pistol-gripped stylus 2 mm in diameter in the center of a 4 mm hole. The stylus was held in the dominant hand with the arm outstretched. The test objective was to avoid touching the sides of the hole with the stylus. The test was one minute in length, and was scored as the amount of time (sec) on target, i.e., when the pointer was not touching the sides (13). Subjects practiced the arm-hand steadiness test for four days during the week prior to the 45 hour simulator exercise, performing 10 trials each day.

### Questionnaire Data

On the first day of testing, subjects completed questionnaires regarding previous injuries and self-motivation (4). A Profile of Mood States questionnaire (19) and a pain and soreness questionnaire (12) were completed daily to provide a baseline measurement for comparison to questionnaires completed during the 45 hour exercise. The pain, soreness and discomfort questionnaire requires subjects to rate their level of pain, soreness and discomfort for the front and back of 11 body sections on a scale of 0 (none) to 5 (extreme).

## SIMULATOR EXERCISE

Two 8 man crews (5 crewmen and 3 gunners) and 2 crew chiefs participated in two separate 45 hour exercises. All participants were experienced field artillerymen. Each of the 10 crewmen completed six, 7.5 hour cycles. Each cycle consisted of three, 90 minute active positions (4.5 hours) and two, 90 min resting positions (3 hours). One 7.5 hour cycle with the order of rotation is illustrated in Figure 1. In the #1 position the crewman loaded and fired the

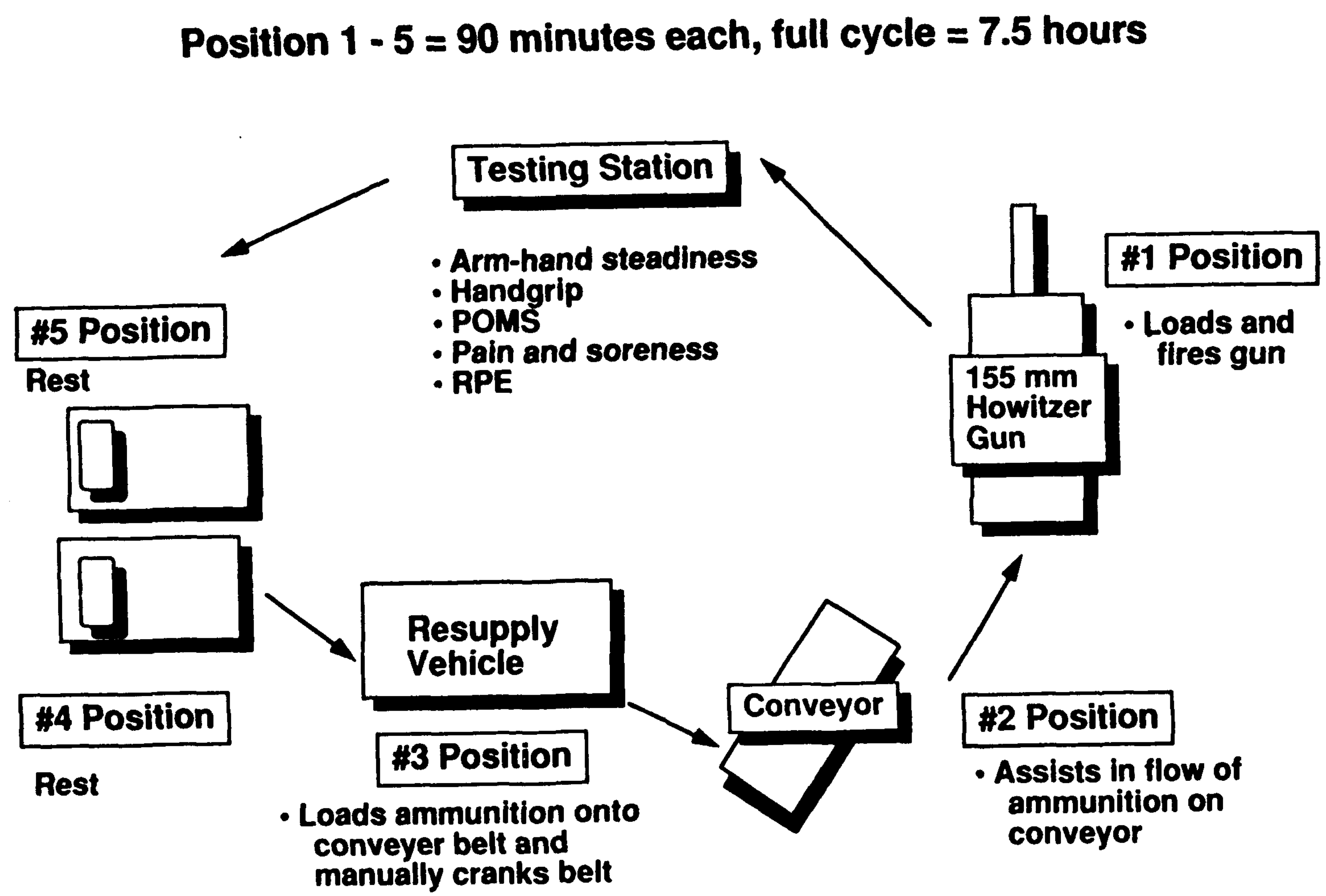



Figure 1. Personnel rotation diagram.

gun. In the #2 position the crewman was located between the gun and supply vehicle to assist in the flow of ammunition along the conveyor belt. The #3 position was in the supply vehicle placing the projectiles and powder bags onto a conveyor belt and operating a manual crank to move a continuous supply of projectiles into the gun. Positions #1, #2 and #3 each involved 75 min of activity followed by 15 min of rest. The rest period allowed for rotation of subjects and post-cycle testing. Post-cycle testing of the subject in the #1 position was completed during the 15 min 'rest period' at the end of the #1 position. The tests are described in a later section of this report. The two positions marked rest (Figure 1) permitted crewmembers three hours of continuous rest following completion of the #1 position and post-cycle testing. A quiet area with cots was available, but soldiers were not required to stay there.

In addition to the crewman in the #1 position, there were 3 others inside the howitzer. Two gunners adjusted the barrel and the crew chief supervised. The three gunners in each crew rotated on for 6 hours and off for 3 hours, so that 2 gunners were in the howitzer at all times. Crew chiefs worked 12 hour shifts. No measurements were made on the gunners or the crew chiefs.

Four fire plans were prepared by the Field Artillery School Cadre designating the timing, number of rounds to be fired, and angle and deflection of the barrel. Each grouping of rounds within the fire plan was referred to as a fire mission. Fire missions consisted of one, two or eight rounds. Four different fire plans were used, so the exact timing of the fire missions would not be anticipated by the subjects. Mission time, the main measure of howitzer loading performance, was calculated as the sum of the elapsed time between call in and completion of the fire mission. The Fire Direction Control Officer recorded the time each fire mission was radioed to the crew chief. As soon as the mission (series of rounds) was completed the crew chief radioed the Fire Direction Control Officer, who recorded the completion time. The difference between the start and completion of the fire mission was calculated and summed over the 75 min for each subject in the #1 position. Each plan had an equal number of rounds fired (40) and was completed within 75 min. As part of the 40 round total, each fire plan contained a series of four missions of two rounds each (four 2-round

missions) separated by two minutes which was called in at minute 30, and a final 8 round mission. The times from mission call in to mission completion for these two series were referred to as four-2 round time and 8 round time, respectively.

## Physiological Measurements

The physiological measurements made during the simulator exercise were heart rate and oxygen uptake. Heart rate was recorded in one minute increments throughout the 45 hours with a UNIQ Heartwatch system. Heart rate and $\dot{V}O_2$ data collected during the peak $\dot{V}O_2$ test were used to produce an individualized equation to predict oxygen uptake from heart rate during the simulator exercise. Each subject performed three submaximal loads during the peak $\dot{V}O_2$ test. Each 30 sec sample collected after the second minute of submaximal exercise was used to produce a linear regression equation. The regression equation for each subject was then applied to the heart rate data collected during the exercise to estimate energy cost. The oxygen uptake of the #1 position crewman was directly measured twice during each 75 min cycle with an on-line oxygen uptake system. These oxygen uptake values were used to validate the oxygen uptake predicted from heart rate during the four-2 round fire missions (approximately 30 minutes into the #1 position), and during the 8 round fire mission at the end of the fire plan.

## Post-cycle Measurements

Immediately upon completion of 75 min of work at the #1 position, crewmen rated their perceived exertion (RPE) for the upper body, the lower body and overall based on the category ratio scale (3). Next, they completed the arm-hand steadiness test, the isometric handgrip strength test, the Profile of Mood States questionnaire and a pain, soreness and discomfort questionnaire.

# DATA ANALYSIS

Data from the two crews were pooled for all analyses. Means and standard deviations were calculated for each measurement at each time. Repeated

measures analysis of variance was used to assess changes in arm-hand steadiness, pain, soreness and discomfort, mood state, handgrip strength and RPE over the six cycles of the simulator exercise.

# RESULTS

## INJURIES

Two of the ten crewmen were injured. One subject hit his head and developed a hematoma while entering the gun for cycle 2. He was replaced, but the substitute's data is not included in the analyses. A second subject pinched his finger between a round and the loader during minute 42 of cycle 6. Some post-cycle 6 data and approximately 30 min of heart rate data are not available for this subject. An estimation of the energy cost of this 30 min was based on the relationship between the energy cost of the first 42 min and final 30 minutes of previous cycles using linear regression. This subject's data are included whenever possible. Two subjects had a malfunctioning heartwatch during one cycle of the simulator exercise and on one subject we lost two cycles of data. Missing data were interpolated using a cubic spline function (1). The estimated energy cost analyses will be based on an n of nine.

## PRE-EXERCISE MEASUREMENTS

### Subject Physical Characteristics

The physical characteristics of the nine #1 men (mean, sd, and range) are listed in Table 1. The self-motivation score was 139.5 ± 16.1. This was comparable to a similar sample of field artillerymen whose scores averaged approximately 145 and ranged from 130 to 168 (11).

Table 1. Physical characteristics of test subjects (n=9).

| | Mean | SD | Range |
|---|---|---|---|
| Age (yrs) | 20.5 | 2.3 | 19-26 |
| Height (cm) | 178.0 | 9.5 | 163-188 |
| Weight (kg) | 81.6 | 14.3 | 63-108 |
| Body fat (%) | 18.2 | 6.7 | 9-26 |
| fat free mass (kg) | 65.7 | 8.5 | 55-81 |
| arm length (cm) | 82.3 | 6.2 | 74-92 |
| leg length (cm) | 94.6 | 7.2 | 86-103 |
| seated height (cm) | 92.0 | 3.7 | 86-98 |

## peak $\dot{V}O_2$

The peak oxygen uptake test for 155 mm Howitzer loading is reported in greater detail in a separate report (26). Peak oxygen uptake for howitzer loading is listed in Table 2. When subjects were asked to load 10 rounds as rapidly as possible during the final load of the peak $\dot{V}O_2$ test, the mean rate of loading was 26.8 ± 1.7 seconds per round.

Table 2. Peak oxygen uptake for howitzer loading ($\bar{X}$ ± SD, n=9).

| peak $\dot{V}O_2$ ($l \cdot min^{-1}$) | peak $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) | $\dot{V}E$ ($l \cdot min^{-1}$) | Heart rate ($b \cdot min^{-1}$) |
|---|---|---|---|
| 3.42 ± 0.67 | 42.3 ± 7.2 | 102.5 ± 19.7 | 187.8 ± 12.3 |

## Muscular strength

The mean ± sd for bench press, prone row and incremental dynamic lift (IDL) are listed in Table 3.

Table 3. Muscular strength measurements ($\bar{X} \pm$ SD, n=9).

| IDL (kg) | Isometric Handgrip (N) | Bench Press* (kg) | Prone Row* (kg) |
|---|---|---|---|
| 89.9 ± 17.0 | 574.3 ± 112.2 | 67.9 ± 32.0 | 70.7 ± 29.6 |

(*n=8)

## Physical fitness test

Results from the Army physical fitness test (2 mi run, push-ups and sit-ups) are listed in Table 4. The mean raw scores (time and number of sit-ups and push-ups) are listed, as well as the mean standardized, age weighted method of scoring from 0-100 points per event.

Table 4. Army physical fitness test results ($\bar{X} \pm$ SD, n=9).

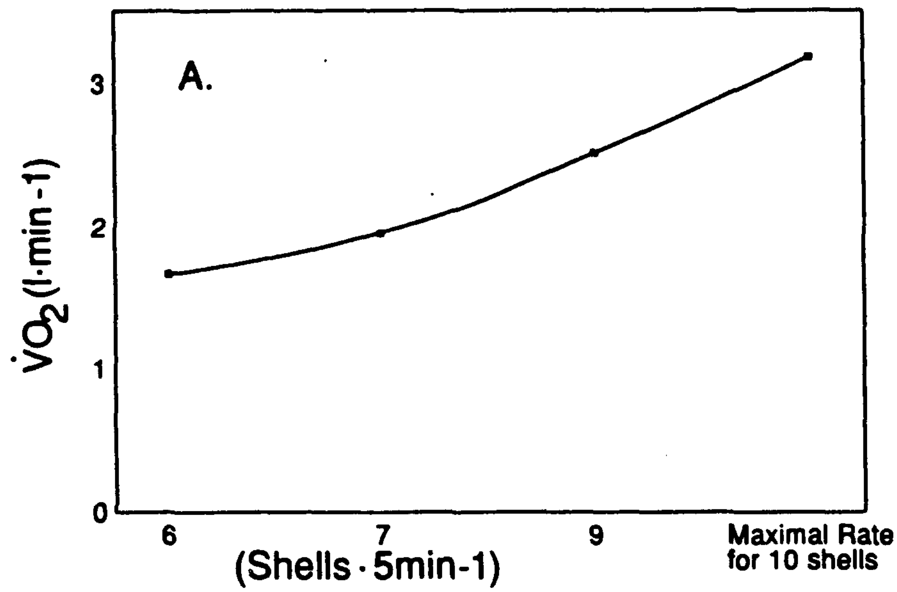
| | Push-ups | Sit-ups | 2 mile run |
|---|---|---|---|
| Raw Score | 51.8 ± 3.4 | 57.7 ± 7.7 | 15:24 ± 1:18 |
| APFT Points | 70 ± 13 | 67 ± 8 | 66.4 ± 13.9 |

## PREDICTED ENERGY COST OF #1 POSITION

The energy cost for the simulator exercise was predicted from the heart rate-$\dot{V}O_2$ curve obtained during the peak $\dot{V}O_2$ test. The peak $\dot{V}O_2$ test and heart rate-$\dot{V}O_2$ relationship for one subject are shown in Figure 2. To assess the accuracy of our equations, the actual oxygen uptake was collected at two points during the simulator exercise (the four-2 round missions and the final 8 round mission) and correlated with the predicted oxygen uptake. This correlation was 0.78 ($p<.001$) as shown in Figure 3. The heart rate, actual oxygen uptake, predicted oxygen uptake and the difference between the two for the four-2 round missions and the 8 round missions are listed by cycle in table 5.

The predicted energy cost, relative exercise intensity (percentage of maximal oxygen uptake) and mission completion time for each cycle are listed in Table 6. Energy cost decreased significantly ($p<.01$) from cycle 1 to cycles 5 and 6. The mean exercise intensity (%$\dot{V}O_2$max) decreased significantly ($p<.01$) during the simulator exercise from cycle 1 to 6. The mission completion time during the cycle also decreased significantly ($p<.01$) from cycle 1 to 6.

The most stressful part of the simulator exercise was the final 8 round mission. The exercise intensity during this period averaged 75.8% of task specific peak $\dot{V}O_2$. While in the #1 position, heart rate was greater than 75% of maximum for an average of 16 min, between 50 and 75% of maximum for 46 min and less than 50% of maximum for 12 min. This did not change significantly from cycle to cycle.



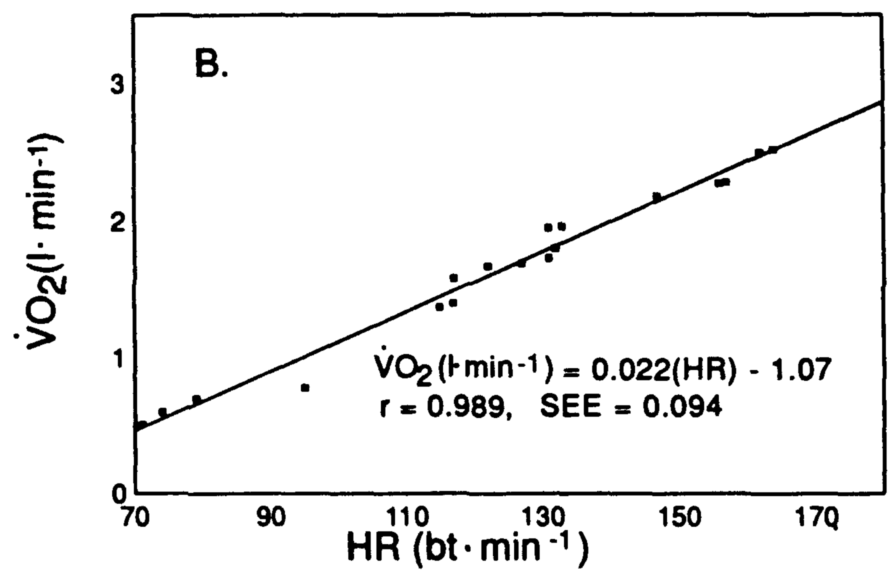




Figure 2. Peak $\dot{V}O_2$ test (A) and heart rate to $\dot{V}O_2$ relationship (B) for one subject.

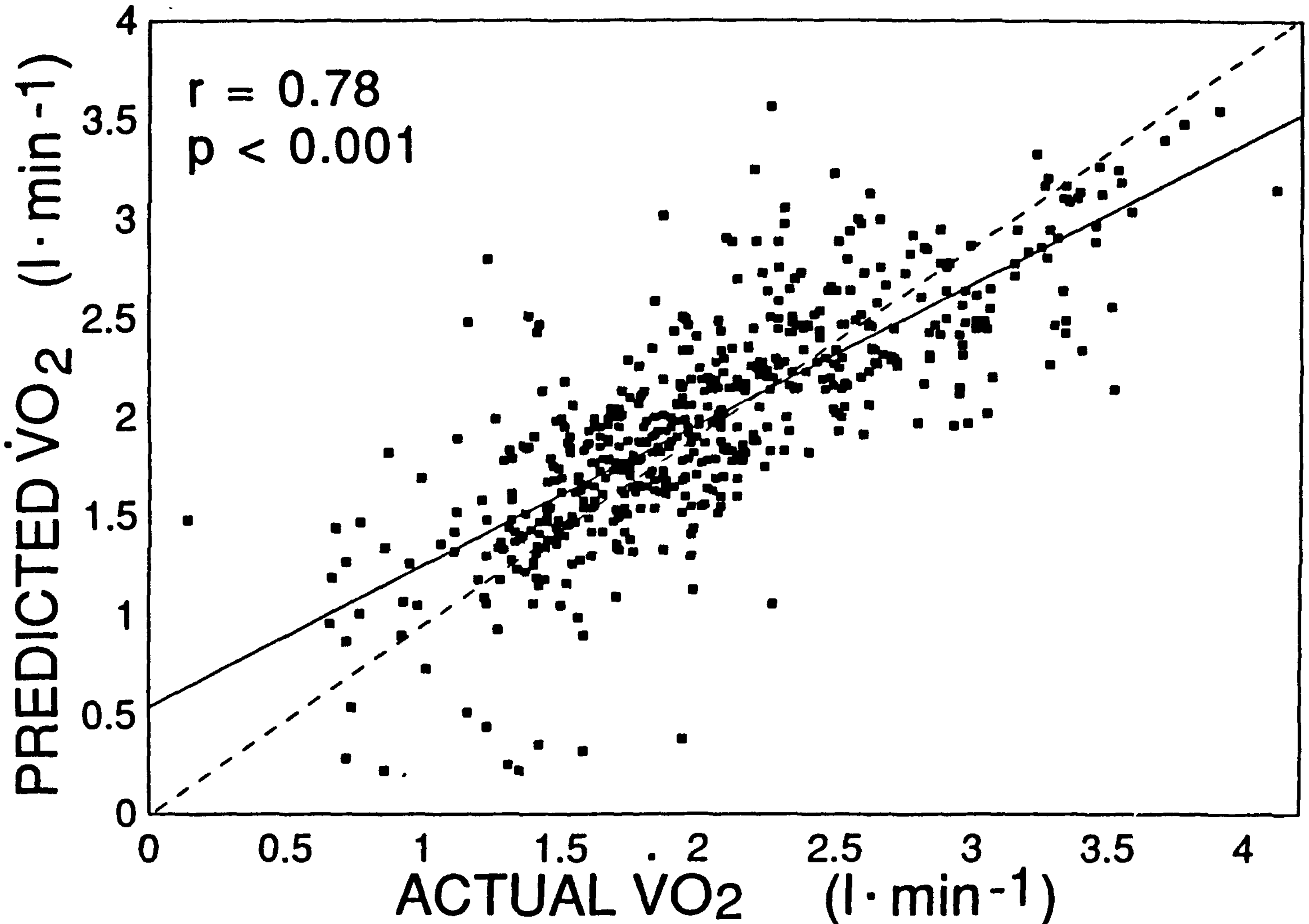



Figure 3. Scatterplot of actual vs predicted $\dot{V}O_2$.

Table 5. Physiological measurements and timing of the four 2-round (4-2 rd) missions and the 8 round (8 rd) missions for each of six cycles in the #1 position (n=6).

| Cycle | Mission type | Mission time (min) | Heart rate ($b \cdot min^{-1}$) | Actual $\dot{V}O_2$ ($l \cdot min^{-1}$) | Predicted $\dot{V}O_2$($l \cdot min^{-1}$) | Actual-Predicted ($l \cdot min^{-1}$) | Actual-Predicted (%) |
|---|---|---|---|---|---|---|---|
| 1 | 4-2 rd | 5.5 ± 0.4 | 153.7 ± 15.4 | 1.82 ± .21 | 1.96 ± .24 | 0.14 | 7.7 |
| | 8 rd | 4.8 ± 0.6 | 167.9 ± 12.1 | 2.39 ± .33 | 2.26 ± .24 | -0.13 | -5.4 |
| 2 | 4-2 rd | 5.3 ± 0.9 | 144.8 ± 10.4 | 1.72 ± .14 | 1.80 ± .08 | 0.08 | 4.7 |
| | 8 rd | 4.5 ± 0.4 | 162.1 ± 16.9 | 2.20 ± .18 | 2.11 ± .16 | -0.09 | -4.1 |
| 3 | 4-2 rd | 5.2 ± 1.5 | 147.3 ± 15.8 | 1.86 ± .19 | 1.81 ± .16 | -0.05 | -2.7 |
| | 8 rd | 4.2 ± 0.7 | 176.5 ± 17.6 | 2.64 ± .44 | 2.41 ± .32 | -0.23 | -8.7 |
| 4 | 4-2 rd | 4.9 ± 0.6 | 148.4 ± 17.9 | 1.76 ± .22 | 1.85 ± .28 | 0.09 | 5.1 |
| | 8 rd | 4.1 ± 0.5 | 165.4 ± 12.0 | 2.47 ± .24 | 2.21 ± .23 | -0.26 | -10.5 |
| 5 | 4-2 rd | 4.6 ± 0.6 | 126.1 ± 14.8 | 1.59 ± .27 | 1.47 ± .18 | -0.12 | -7.5 |
| | 8 rd | 4.4 ± 0.8 | 151.0 ± 14.6 | 2.24 ± .43 | 1.96 ± .34 | -0.28 | -12.5 |
| 6 | 4-2 rd | 5.0 ± 1.3 | 138.5 ± 12.9 | 1.70 ± .25 | 1.69 ± .27 | -0.01 | -0.6 |
| | 8 rd | 4.4 ± 0.5 | 156.5 ± 10.0 | 2.29 ± .24 | 2.04 ± .17 | -0.25 | -10.9 |

Table 6. Energy cost, cycle time, relative exercise intensity (% peak $\dot{V}O_2$) and mission completion time (mission time) during the six cycles (mean ± sd, n=9)

| Cycle | Energy cost ($kcal \cdot min^{-1}$) | Cycle time (min) | % peak $\dot{V}O_2$ | Mission time (min) |
|---|---|---|---|---|
| 1 | 8.0 ± 1.3 | 73.2 | 48.5 ± 8.4 | 28.1 ± 1.6 |
| 2 | 7.0 ± 1.6 | 72.9 | 41.9 ± 6.7 | 25.7 ± 2.1 |
| 3 | 7.1 ± 1.6 | 72.1 | 43.0 ± 7.7 | 24.3 ± 3.4[1] |
| 4 | 6.9 ± 1.7 | 72.8 | 41.8 ± 9.3 | 24.5 ± 1.9[1] |
| 5 | 6.0 ± 2.0[1] | 73.0 | 35.8 ± 9.3[1] | 24.3 ± 3.0[1] |
| 6 | 6.2 ± 2.1[1] | 72.4 | 37.1 ± 13.2[1] | 24.3 ± 3.3[1] |

[1] Significantly different than cycle 1 (p<.01).

## MEASURES MADE FOLLOWING #1 POSITION

Following performance of the #1 position, subjects were asked to provide a rating of perceived exertion (RPE) for the upper body, the lower body and overall. The scale is from 1 (very, very light) to 10 (very, very hard) or any number greater than 10 (maximal). These results are listed in Table 7. The RPE did not rise rapidly, however, all three RPE measurements were significantly greater at the end of cycle 6 than at the end of earlier cycles.

Table 7. RPE for the upper and lower body and overall during the simulator exercise (mean ± sd, n=8).

| cycle | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| upper | 4.5 ± 2.1 | 4.2 ± 1.7 | 4.4 ± 1.3 | 4.6 ± 1.3 | 5.4 ± 1.7 | 5.7 ± 1.5[1] |
| lower | 3.9 ± 2.5 | 2.9 ± 2.0 | 3.2 ± 1.8 | 3.9 ± 1.9 | 4.1 ± 2.0 | 4.6 ± 2.2[2] |
| overall | 4.4 ± 2.1 | 4.4 ± 2.2 | 4.7 ± 2.1 | 5.0 ± 2.0 | 5.5 ± 1.7 | 5.9 ± 2.2[3] |

[1] Significantly different from cycles 1, 2 and 3, (p<.05).

[2] Significantly different from cycle 2, (p<.05).

[3] Significantly different from cycles 1 and 2, (p<.05).

Arm-hand steadiness was measured on each of four days during the week preceding the simulator exercise. No significant difference was found across pre-exercise days, therefore a mean of all four days was used as the baseline measurement. There was no significant change in arm-hand steadiness during the course of the exercise, as illustrated in Figure 4.

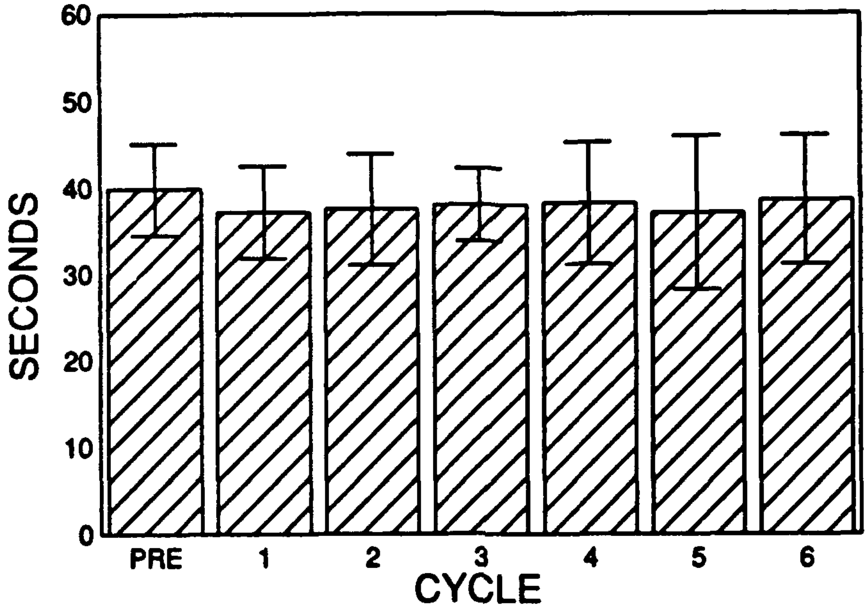



Figure 4. Results of the arm-hand steadiness test *measured* pre-exercise and following each cycle in the #1 position.

There was a significant decrease over time in isometric handgrip strength from cycle 1 to cycle 6. These results are listed in Table 8.

Table 8. Isometric handgrip strength (N) pre-exercise (Pre) and cycles one through six ($\bar{X}$ and SD, n=8)

| | | cycle | | | | | |
|---|---|---|---|---|---|---|---|
| | Pre | 1 | 2 | 3 | 4 | 5 | 6 |
| Mean | 592.0 | 607.1 | 568.4 | 556.1 | 558.5 | 558.4 | 547.0[1] |
| SD | 105.8 | 129.1 | 142.8 | 120.4 | 114.1 | 123.9 | 114.9 |

[1] Significantly different than cycle 1 (p<.05).

The profile of mood states (POMS) was evaluated for five days prior to the simulator exercise. There were no significant differences across the 5 pre-exercise days, therefore, a mean of the 5 days was selected for use as a baseline measure. Average POMS scores for cycles 1 through 6 are listed in Table 9. Tension and fatigue increased during the simulator exercise, while vigor decreased.

Table 9. Profile of mood states before and following cycles one through six of the simulator exercise (mean and SD, n=9).

| | Pre | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Tension | 6.6 | 5.2 | 5.8 | 6.3 | 6.5 | 8.2 | 9.2[1] |
| | 2.6 | 3.6 | 3.6 | 2.8 | 2.6 | 2.6 | 5.0 |
| Depression | 3.8 | 1.7 | 2.1 | 2.0 | 1.7 | 2.5 | 2.8 |
| | 2.6 | 2.2 | 2.2 | 2.6 | 2.3 | 3.8 | 4.0 |
| Anger | 7.9 | 4.2 | 4.1 | 3.7 | 4.9 | 5.4 | 6.4 |
| | 4.8 | 4.0 | 4.1 | 4.2 | 4.4 | 5.6 | 6.0 |
| Vigor | 15.0 | 15.4 | 11.7 | 12.8 | 11.7 | 10.3[2] | 10.0[3] |
| | 4.7 | 4.7 | 3.8 | 6.9 | 6.4 | 4.8 | 4.9 |
| Fatigue | 3.1 | 2.9 | 4.3 | 4.8 | 6.0 | 8.5[4] | 9.2[4] |
| | 2.9 | 2.8 | 3.2 | 2.9 | 2.7 | 4.0 | 4.4 |
| Confusion | 4.9 | 3.1 | 3.5 | 3.1 | 3.8 | 4.0 | 4.5 |
| | 2.7 | 2.1 | 2.6 | 1.9 | 2.2 | 2.2 | 2.8 |

[1] Significantly different from cycle 1 and 2, ($p<.05$).

[2] Significantly different from baseline, ($p<.05$).

[3] Significantly different from baseline and cycle 1, ($p<.05$).

[4] Significantly different from baseline and cycles 1-3, ($p<.05$).

Levels of pain, soreness and discomfort were rated by subjects daily for 5 days during the pre-exercise week. The pre-exercise measures for the front of the chest, thigh and lower leg were significantly greater on day 3 than on day 1. The Army physical fitness test (APFT) was performed 3 hours prior to the pain, soreness and discomfort questionnaire administration on day 3. As the APFT significantly affected the ratings of pain, soreness and discomfort of these body parts, scores for day 3 were not included in the pre-exercise means of these measures resulting in a four day average for the pre-exercise score. For all other measures the pre-exercise score is the mean of all five days. The results of the pain, soreness and discomfort questionnaire completed at the end of each cycle are listed in Tables 10 and 11. The results indicate increasing levels of pain, soreness and discomfort in the arm and shoulder areas. There was no increase in the back, abdominal or lower body areas. Figure 5 shows the areas where the scores increased significantly.

Table 10. Response to the pain, soreness and discomfort questionnaire for the front of the body, completed before and during the simulator exercise (mean (sd), n=9).

| cycle | pre | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Neck | 1.1 (0.2) | 1.1 (0.3) | 1.0 (0.0) | 1.0 (0.0) | 1.0 (0.0) | 1.5 (0.9) | 1.7 (1.3) |
| shoulder | 1.7 (0.5) | 1.4 (1.0) | 1.5 (1.1) | 1.3 (0.7) | 2.1 (1.4) | 2.5[1,2] (1.4) | 2.5[1,2] (1.7) |
| upper arm | 1.3 (0.4) | 1.7 (1.1) | 1.7 (1.1) | 1.5 (0.9) | 1.9 (1.4) | 2.3[3] (1.3) | 2.5[2,3] (1.5) |
| Forearm | 1.0 (0.0) | 1.3 (1.0) | 1.2 (0.7) | 1.2 (0.7) | 1.7 (1.4) | 2.2[3] (1.3) | 2.7[4] (1.9) |
| hand | 1.1 (0.2) | 1.7 (1.1) | 2.8[3] (1.6) | 2.5 (1.6) | 2.9[3] (1.6) | 3.1[3] (1.4) | 2.7[3] (1.5) |
| chest | 1.0 (0.1) | 1.0 (0.0) | 1.1 (0.3) | 1.2 (0.7) | 1.3 (1.0) | 1.4 (1.3) | 1.5 (1.3) |
| abdomen | 1.0 (0.1) | 1.0 (0.0) | 1.1 (0.3) | 1.2 (0.7) | 1.3 (1.0) | 1.4 (1.3) | 1.5 (1.3) |
| hips | 1.0 (0.0) | 1.0 (0.0) | 1.1 (0.3) | 1.2 (0.7) | 1.3 (1.0) | 1.5 (1.3) | 1.4 (1.3) |
| thigh | 1.1 (0.2) | 1.0 (0.0) | 1.3 (0.7) | 1.2 (0.7) | 1.5 (1.0) | 1.7 (1.3) | 1.8 (1.4) |
| shin | 1.1 (0.2) | 1.0 (0.0) | 1.3 (0.7) | 1.3 (0.7) | 1.3 (1.0) | 1.4 (1.3) | 1.4 (1.3) |
| foot top | 1.0 (0.1) | 1.0 (0.0) | 1.1 (0.3) | 1.2 (0.7) | 1.3 (1.0) | 1.4 (1.3) | 1.4 (1.3) |

[1] Significantly different from cycle 1, (p<.05).

[2] Significantly different from cycle 3, (p<.05).

[3] Significantly different from baseline, (p<.05).

[4] Significantly different from baseline, cycle 1, 2 and 3, (p<.05).

Table 11. Response to the pain, soreness and discomfort questionnaire for the back of the body, completed before and during the simulator exercise (mean (sd), n=9).

| cycle | pre | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Neck | 1.2 (0.3) | 1.2 (0.4) | 1.2 (0.4) | 1.2 (0.4) | 1.3 (0.7) | 1.8 (1.0) | 2.1 (1.5) |
| shoulders | 1.3 (0.4) | 1.4 (1.0) | 1.4 (0.9) | 1.4 (0.9) | 2.0 (1.4) | 2.0 (1.3) | 2.3[1] (1.3) |
| upper arm | 1.3 (0.4) | 1.9 (1.4) | 1.7 (1.1) | 1.5 (1.1) | 2.0 (1.5) | 2.0 (1.5) | 2.4[2] (1.6) |
| forearm | 1.0 (0.0) | 1.7 (1.3) | 1.5 (1.1) | 1.5 (1.1) | 1.8 (1.6) | 2.3[2] (1.4) | 2.0[2] (1.5) |
| hand | 1.0 (0.1) | 1.1 (0.3) | 2.0 (1.4) | 1.5 (1.1) | 2.1 (1.7) | 2.2 (1.5) | 2.1 (1.4) |
| upper back | 1.1 (0.3) | 1.1 (0.3) | 1.2 (0.4) | 1.3 (0.7) | 1.4 (1.0) | 1.7 (1.3) | 1.5 (1.3) |
| lower back | 1.4 (0.5) | 1.2 (0.4) | 1.3 (0.5) | 1.4 (0.7) | 1.8 (1.1) | 1.8 (1.4) | 2.2 (1.4) |
| buttocks | 1.1 (0.3) | 1.1 (0.3) | 1.1 (0.3) | 1.3 (0.7) | 1.4 (1.0) | 2.0 (1.4) | 1.9 (1.5) |
| thigh | 1.1 (0.1) | 1.0 (0.0) | 1.1 (0.3) | 1.3 (0.7) | 1.4 (1.0) | 1.8 (1.4) | 1.7 (1.4) |
| calf | 1.1 (0.1) | 1.0 (0.0) | 1.1 (0.3) | 1.2 (0.7) | 1.3 (1.0) | 1.4 (1.3) | 1.4 (1.3) |
| foot bottom | 1.0 (0.0) | 1.0 (0.0) | 1.1 (0.3) | 1.2 (0.7) | 1.3 (1.0) | 1.4 (1.3) | 1.4 (1.3) |

[1] Significantly different from cycle 1.
[2] Significantly different from baseline.

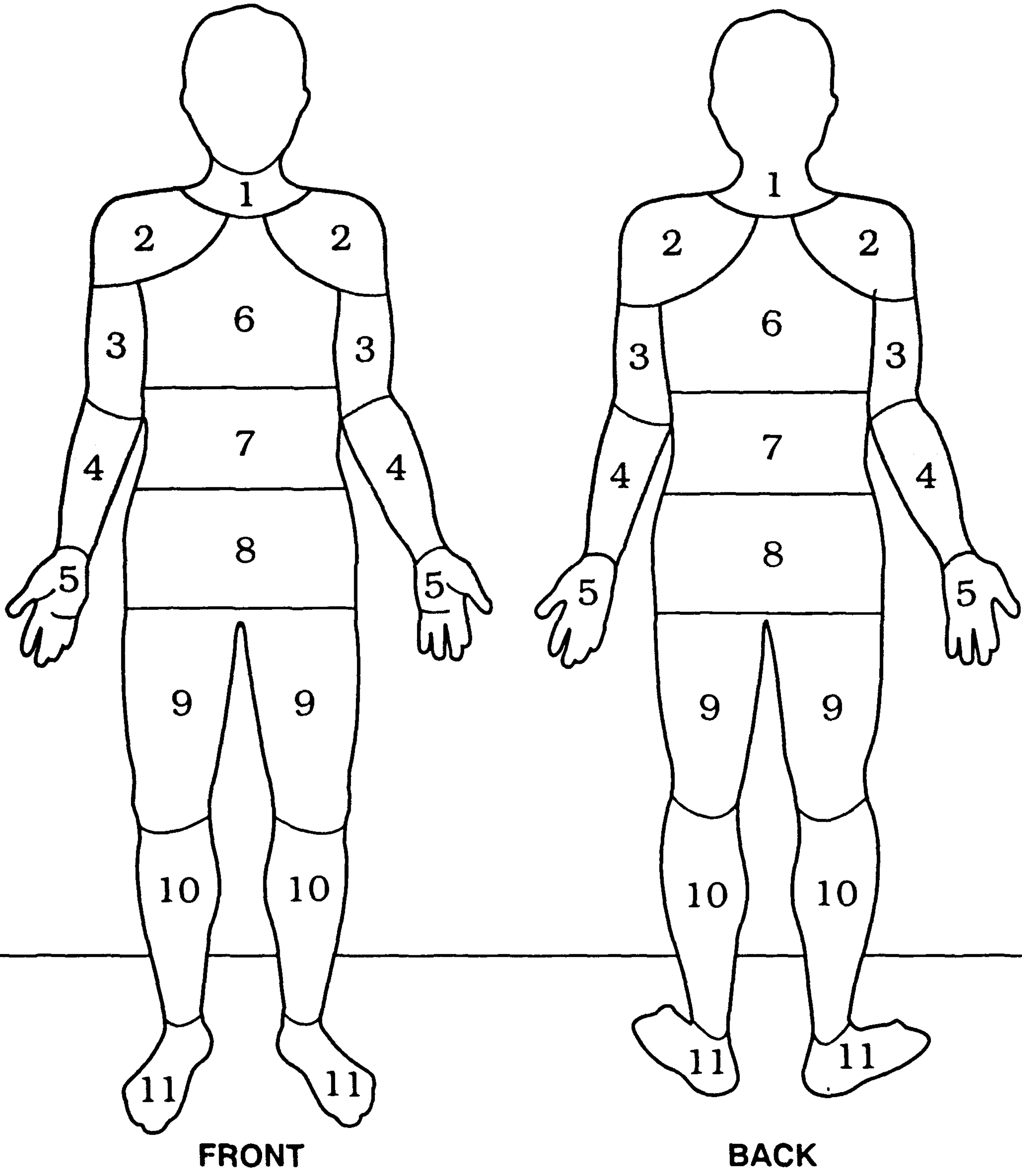



Figure 5. Shaded areas denote significant increases in subjective reports of pain, soreness and discomfort ($p<.05$) during the simulator exercise.

## CORRELATIONAL ANALYSIS

Pre-exercise profiling measures were correlated with performance measurements during the simulator exercise. These results are listed in Table 12. Subjects with a higher aerobic capacity and those who had greater lifting and handgrip strength tended to expend more energy during the simulator exercise. Subjects with higher lifting strength and bench press strength tended to have faster 8 round times.

Table 12. The relationship between howitzer loading performance measures and descriptive measures of body size, strength and aerobic capacity (n=9).

| | 8 round time[1] | Mission time[1] | Sum Kcals[1] |
|---|---|---|---|
| peak $\dot{V}O_2$ ($l \cdot min^{-1}$)[1] | -.41 | -.30 | .69* |
| 10 round time[1] | -.13 | .28 | -.11 |
| dynamic lift | -.76* | -.21 | .71* |
| handgrip[1] | -.43 | -.60 | .71* |
| bench press[2] | -.75* | -.22 | .69 |
| prone row[2] | -.48 | -.55 | .69 |
| height | -.36 | -.64 | .56 |
| weight | -.53 | -.27 | .56 |
| arm length | -.28 | -.42 | .44 |
| leg length | .00 | -.81** | .35 |
| seated height | .35 | -.46 | .05 |
| % body fat | -.51 | .09 | .37 |
| lean body mass | -.47 | -.33 | .53 |
| mission time[1] | .05 | 1.00 | -.49 |
| energy cost (kcals)[1] | -.75* | -.49 | 1.00 |

* ($p<.05$), ** ($p<.01$)
[1] Mean of cycles 1 through 6.
[2] n=8

# DISCUSSION

The crewmember energy cost for howitzer loading has not been reported in the literature. Energy cost is dependent on exercise intensity, determined by the rate of fire. The European I, Sequence 2A Scenario (29) envisions a maximum firing rate of 500 rounds/day, with an average rate of 275 rounds/day. The present study utilized a rate of 640 rounds/day continuously for 45 hours, and thus would be considered very intense. Many other tasks typically performed by field artillerymen (occupying and displacing the gun, setting up camouflage, rearming and refueling, etc) were not performed. While this may have resulted in some loss of realism, this study did examine the energy cost of loading and firing of the gun and how this task affected soldier perceptions of effort, pain, soreness and discomfort and physiological performance.

In the ergonomics literature, the average exercise intensity for an 8 hour work day ranges from 21-50% $\dot{V}O_2max$ depending on the nature of the exercise and the exercise mode used to assess $\dot{V}O_2max$ (8,9,14,16). The specific recommendation from the National Institute of Occupational Safety and Health is 33% of $\dot{V}O_2max$ assessed by treadmill or cycle ergometer exercise (20). During the first 75 min cycle of simulated loading and firing, subjects expended 586 kcal, while firing 40 rounds over a 28 min period. This represented 49% of their task specific peak $\dot{V}O_2$ for howitzer loading. In the final (sixth) 75 min cycle, energy cost averaged 448 kcals over a 24 min period, or 37% peak $\dot{V}O_2$ for howitzer loading. If the relationship between cycle ergometer $\dot{V}O_2max$ and repetitive lifting $\dot{V}O_2max$ is assumed to be the same for cycle ergometer $\dot{V}O_2max$ and howitzer loading peak $\dot{V}O_2$, the exercise intensity relative to cycle ergometer $\dot{V}O_2max$ would be 42% for cycle one and 33% for cycle six (25). During cycle 1 these soldiers (on average) were exercising at the highest level recommended. However, by the fifth cycle the exercise intensity was within recommended levels and the fire missions were completed in a shorter time period. A decreased energy cost combined with faster mission completion times indicates an increase in efficiency of loading.

The average exercise intensity for the simulator exercise reached an acceptable level as soldiers improved their loading efficiency. This improved efficiency was not found during the 8 round missions. The exercise intensity for this period was extremely high and did not change over the course of the simulator exercise. When averaged over six cycles exercise intensity was nearly 76% of peak $\dot{V}O_2$ during the final 8 round missions. Soldiers were only required to exercise at this intensity for a short time period (< 5 min). The NIOSH guideline of 33% $\dot{V}O_2max$ allows for short intense bouts of up to 3.0 ($l \cdot min^{-1}$). The energy cost for the 8 round mission did not (on average) exceed this limit.

Despite an increase in efficiency, there were indications of degradation of the soldiers' physical capabilities toward the end of the 45 hour exercise. There was a decrease in handgrip strength and soldiers reported decreased vigor, increased fatigue, and perceived exertion, and higher levels of pain, soreness and discomfort in the shoulders, arms and hands. It is possible that a longer exercise period would have resulted in performance degradation.

The RPE reported by subjects following performance of the #1 position increased significantly during the course of the simulator exercise. Therefore, subjects were expending less energy, while perceiving the exercise to be more difficult. Examination of the actual oxygen uptake collected during the four-2 round missions revealed a significant decrease in $\dot{V}O_2$ from cycles 1 and 3 to cycle 5. No differences were found in $\dot{V}O_2$ for the 8 round mission. Martin and Gaddis (17) reported that RPE increases with sleep deprivation even though work intensity and cardiorespiratory measures do not increase. The stress produced by continuous operations involving repeated bouts of high intensity exercise may also result in higher ratings of perceived exertion even though the overall exercise intensity decreased.

During resupply operations, soldiers must defend themselves from sniper attack. Arm-hand steadiness may be an important factor in rifle firing ability, since small movements of the weapon may influence shooting accuracy (12). In the present study arm-hand steadiness did not change during the 45 hour exercise. Previous studies of sustained infantry operations have found no

significant decreases in marksmanship when adequate sleep is obtained (10,21). Knapik et al. (12) reported that post-exercise rifle firing accuracy decreased 26% for number of targets hit following a maximal effort 20 km road march lasting more than 5 hours. It may be that the discontinuous nature of the loading exercise performed in this study did not result in sufficient stress to produce a decrease in arm-hand steadiness.

The soldiers in this study were slightly below average (within one standard deviation) on all three events of the Army physical fitness test. The average push-up score was 2% below, the average sit-up score was 7% lower, and the two mile run time was 4.6% slower than the reported mean for their age group (5). The soldiers were aware that the test scores would not be made part of their permanent record, and the test was administered during the pre-dawn hours of an unusually cold day (<30°F). The discomfort and lack of career significance of the test may have resulted in poorer performances than if the test were to be made part of their permanent record.

The incremental lifting performance was 32% greater (29 kg) than that reported for a large group of aged matched males (28), and 14% greater (12 kg) than that of a previous group of field artillerymen (22). The above average lifting strength of the subjects may have contributed to their ability to withstand the effects of fatiguing lifting exercise. Upper body strength (dynamic lift, r=-0.76 and bench press, r=-0.75) was highly correlated with 8 round mission time, therefore, subjects with greater upper body strength were able to complete the 8 round mission faster. Subjects with greater upper body strength and those with a higher aerobic capacity tended to expend more energy during the simulator exercise. The higher energy cost during simulator exercise may also be due to a larger quantity of muscle mass active during exercise. Upper body strength may be an important factor in rapid loading and firing of the howitzer, and should be considered when developing strength training programs for this occupational specialty.

Isometric handgrip strength was significantly decreased during the 45 hour simulator exercise. This is in contrast to a study that found an increase in handgrip strength following an 8 day sustained field artillery operation (23). The

increase was attributed to an increase in motivation at the completion of the training exercise, and possibly to a learning effect. In the present study, repeated bouts of high intensity exercise appear to have had a fatiguing effect on handgrip strength, although the decrease was not large.

The psychological state of the soldiers, as measured by the POMS, followed a similar pattern to that of an 8 day field training exercise. Knapik observed significant increases in fatigue and tension following 8 days of continuous artillery operation (11).

## CONCLUSION

This study showed that trained field artillerymen were able to maintain howitzer loading performance for a 45 hour period. Loading exercise became more efficient metabolically, and the work was completed in a shorter time period at the end of the 45 hour exercise. However, the individual perception of effort was increased, as were the reports of pain, soreness and discomfort while muscle strength was decreased. These latter findings suggest that longer exercises (>45 hours) of a similar intensity may cause performance decrements that could impact significantly on the performance of field artillery soldiers. Further studies involving longer exercises could test this hypothesis.

These data have important implications for training field artillery personnel. It has been recommended that soldiers train as they will fight, with training being as realistic as possible (2). The 45 hour exercise reported here was not realistic, but afforded soldiers an opportunity to work at high rates of fire. Loading performance improved as they performed repeated bouts of exercise in the #1 position. It would be extremely expensive to provide this type of experience to soldiers in the field. The Field Artillery School may want to consider a short term high rate of fire exercise in a simulator to improve speed of loading performance. In a battle plan in which artillery pieces move to a location, fire a few rounds and move out, faster mission times could improve the survivability of the crews. The correlation between measures of upper body strength and faster 8 round mission times, combined with the fact that field

artillerymen tend to have greater incremental dynamic lift scores suggests that special attention should be paid to the development of upper body muscle strength in these soldiers.

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